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Constant power threshold—predicting maximal lactate steady state in recreational cyclists

Introduction

Well-being and health benefits are well-established goals to participate in recreational sports (Ley, 2020; Molanorouzi, Khoo, & Morris, 2015). Social recognition, improvements in self-esteem and self-confidence as well as gains in performance and pushing one's own limits are further relevant motives positively impacting compliance to exercise (Deelen, Ettema, & Kamphuis, 2018; Gill, Dowd, Williams, Beaudoin, & Martin, 1996; Kraus et al., 2017; Ley, 2020; Nikolaidis, Chalabaev, Rosemann, & Knechtle, 2019). Thus, for recreational cyclists exercising not only for health reasons but also aiming at improving individual performance, determination of appropriate training zones can be helpful for tailoring individual training programs and for achieving these goals (Jones, Burnley, Black, Poole, & Vanhatalo, 2019). The transition from sustainable to non-sustainable exercise intensities is commonly considered to differentiate between heavy and severe-intensity exercise. This corresponds to the maximal sustainable oxidative metabolic rate and therefore is widely considered a benchmark for prescribing appropriate training zones (Beneke, Hutler, Von Duvillard, Sellens, & Leithauser, 2003; Jones et al., 2019; Jones & Carter, 2000; Mann, Lamberts, & Lambert, 2013). For readability, this transition is referred to as anaerobic threshold (AnT) in the following.

All-out time trials (TT), which target at completing fixed distances in minimum time or generating maximum work in fixed time, do not need expensive equipment and trained staff and thus can be an attractive alternative for recreational athletes. In recent years, TTs experienced a revival under the term functional threshold power, which is the average workload during a prolonged all-out test (Allan & Coggan, 2010; Borszcz, Ferreira Tramontin, & Pereira Costa, 2019; Inglis, Ianetta, Passfield, & Murias, 2020; Jeffries, Simmons, Patterson, & Waldron, 2019; Lillo-Bevia et al., 2019; McGrath, Mahony, Fleming, Raleigh, & Donne, 2021). Capability of all-out TTs for predicting performance and estimating workload at AnT was proven in numerous investigations on experienced, well-trained cyclists (Bentley, McNaughton, Thompson, & Vleck, 2001; Burnley, Doust, & Vanhatlo, 2006; Campbell, Sousa, Ferreira, Assenço, & Simes, 2007; Groslambert et al., 2004; Harnish, Swensen, & Pate, 2001; Sperlich, Haegele, Thissen, Mester, & Holmberg, 2011; Swensen, Harnish, Beitman, & Keller, 1999). Accordingly, TTs are widespread in competitive cycling. However, to the authors' knowledge, TT studies on low to moderately trained cyclists are missing. Moreover, TTs are only occasionally applied for determining AnT and for identifying training zones in recreational sports. This is probably due to following reasons. TT duration should be in the range of 30 min to 75 min since average power output (PO) conforms to output at AnT, whereas mathematical correction is required for longer shorter TTs (Borszcz et al., 2019; Ham & Knez, 2009; Harnish et al., 2001; Inglis et al., 2020; MacInnis et al., 2019; McGhee, Tanner, & Houmard, 2005; Pallares et al. 2020). Pacing prolonged TTs, however, challenges even well-trained and competitive cyclists (Borszcz et al., 2019; Foster et al., 1993; Ham & Knez, 2009; Koning de, Bobbert, & Foster, 1999; Mattern, Kenefick, Kertzer, & Quinn, 2001). This is all the more the case with recreational cyclists who usually do not have specific endurance experiences necessary to properly pace all-out TTs as substantiated by the widespread experience of practitioners that many athletes unexperienced in endurance sports have problems to pace the classical 12 min Cooper test.

Accordingly, in the present investigation TT duration was set to 30 min and to 45 min and TTs were conducted at constant PO in order to limit participants' strain and to eliminate the interfering effects of pacing ability and pacing strategy.

The aim of this study thus was to examine whether constant power threshold (CPT), operationalized as the maximum PO constantly maintainable over 30 min (CPT_{30}) and 45 min (CPT_{45}), is capable of accurately estimating AnT in recreational cyclists. CPT_{30} and CPT_{45} were evaluated against maximal lactate steady state (MLSS), which is commonly regarded to be one of the most accurate tools for identifying AnT (Jones et al., 2019; Legaz-Arrese, Carranza-García, Serrano-Ostáriz, González-Ravé, & Terrados, 2011; Mes-

Table 1 Anthropometric data of participants

	Ages (years)	Height (cm)	Weight (kg)	BMI (kg · m^{-2})
All	23.7 ± 3.7	175.7 ± 9.4	71.1 ± 13.8	22.8 ± 2.5
Female (*N* = 11)	22.9 ± 2.1	169.2 ± 7.0	61.0 ± 7.9	21.2 ± 1.7
Male (*N* = 11)	24.6 ± 4.9	182.3 ± 6.6	81.2 ± 10.7	24.4 ± 2.2
P/d [a]	Ns	< 0.001/1.39	< 0.001/1.46	< 0.001/1.28

d Cohen's d, *Ns* statistically not significant
[a]differences between sexes

sias, Gobatto, Beck, & Manchado-Gobatto, 2017).

Methods

Participants

In all, 25 recreational cyclists participated in this study of whom 22 performed all tests required, so that data of 11 female and 11 male probands were included for analysis. Participants had to meet following inclusion criteria: (1) 20–40 years old, (2) Free from serious diseases, (3) Voluntarily willing to perform exhausting exercise, (4) No endurance competition experience, and (5) Low to moderate aerobic capacity estimated by questioning for physical activity and exercise habits. They were instructed to avoid physical training for at least 48 h prior to testing and to maintain their normal nutritional habits. Research has been conducted ethically according to the principles of the Declaration of Helsinki (Harriss & Atkinson, 2019). All participants approved voluntary participation through written informed consent. The study was approved by the institutional ethics committee of the Medical Faculty of Ruhr University of Bochum, registered office: Heart and Diabetes Center Bad Oeynhausen, NRW.

Exercise testing

Participants performed several constant load TTs, separated by at least 48 h, on an electricially braked cycle ergometer (model Excalibur, Lode, Germany) in a semi-air-conditioned laboratory (temperature: 19–23 °C; humidity: 30–80%). Investigators encouraged probands to cycle as long as possible and to give maximum effort before each TT but not throughout. Information about the time elapsed was given if asked for. Workload of the first TT was estimated to be potentially close to MLSS on the basis of the test persons' self-report. After warming-up for 3 min at 60% of the intended workload, PO was increased to the target PO and kept constant for at maximum 45 min or until TT had to be stopped due to exhaustion. Workload of the following TT was adapted in 10 W steps until CPT_{30} and CPT_{45} were determined.

- Example 1: If the first TT at a workload of 140 W was sustainable for 45 min, the second at 150 W for 38 min and the third at 160 W for 19 min, PO at CPT_{30} and PO at CPT_{45} were 150 W and 140 W, respectively.
- Example 2: If the first TT at a workload of 170 W was maintainable for 41 min, the second at 180 W for 24 min and the third at 160 W for 45 min, PO at CPT_{30} and PO at CPT_{45} were 170 W and 160 W, respectively.
- Example 3: If the first TT at 190 W had to be terminated after 22 min and the second TT at 180 W was maintainable for 45 min, PO at CPT_{30} and PO at CPT_{45} both were 180 W.

Measurements

Capillary blood samples (20 µl) were taken from the earlobe before the TT and from then on every 5 min and analyzed by laboratory staff using an enzymatic-amperometric method (Super GL, Dr. Müller Gerätebau, Germany). Results of the determination of blood lactate concentration (BLC) were not communicated to the participants unless they had finished their last test. PO at MLSS was defined as the highest PO at which BLC increased by no more than 1.0 mmol · l^{-1} between the 10th and 30th min of exercise (Beneke et al., 2003). Mean BLC (BLC_{mean}) was the average of the 10th, 15th, 20th, 25th and 30th min. HR was continuously measured using a HR monitor (Polar Electro, Finland) and visible to the probands and noted every minute. Mean HR (HR_{mean}) was the average from the 10th to 30th min. Cardiovascular drift (CVD) was the increase of HR from the 10th to 30th min. Rate of perceived exertion (RPE) was assessed immediately after cessation of TT on the Borg scale (6–20). In contrast to the original scale, probands were allowed to give RPE in 0.5 steps.

Statistical analysis

IBM SPSS version 27.0 was used to analyze data (IBM., Armonk, NY, USA). Normal distribution was tested using Shapiro–Wilk test. *T*-test and one-way repeated-measures analysis of variance (ANOVA), Bonferroni post hoc test and Greenhouse–Geisser correction were used for identifying and interpreting significant differences of the mean. Statistical significance was set at $P \leq 0.05$ (*) for significant and $P \leq 0.01$ (**) for highly significant. Squared eta (η^2; < 0.06 = small, 0.06–0.14 = medium, > 0.14 = large) and Cohen's d (d; < 0.5 = small, 0.5–0.8 = medium, > 0.8 = large) for independent and dependent variables were calculated to assess effect sizes. Coefficient of determination (R^2), standard error of estimate (SEE) were computed by means of single linear regression analyses. Percentage SEE (%SEE) was SEE divided by PO at MLSS, multiplied by 100. Bland–Altman analyses were applied for determining bias and 95% confidence interval (Bland & Altman, 1999). Data is presented as mean and standard deviation (SD) unless otherwise indicated.

Results

In all, 22 probands conducted two to six (median four) TTs for determining CPT_{30}, CPT_{45} and MLSS. For anthropometric data and physiological parameters at MLSS see **Table 1 and 2**, respectively. Repeated measures ANOVA identified significant differences between MLSS, CPT_{30} and CPT_{45} for PO ($P < 0.001$, $\eta^2 = 0.295$), BLC_{mean} ($P = 0.012$, $\eta^2 = 0.221$), HR_{mean} ($P = 0.024$, $\eta^2 = 0.188$) and RPE ($P = 0.003$, $\eta^2 = 0.238$)

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Constant power threshold—predicting maximal lactate steady state in recreational cyclists

Abstract

Introduction. Prolonged time trials proved capable of precisely estimating anaerobic threshold. However, time trial studies in recreational cyclists are missing. The aim of the present study was to evaluate accuracy and viability of constant power threshold, which is the highest power output constantly maintainable over time, for estimating maximal lactate steady state in recreational athletes.
Methods. A total of 25 recreational athletes participated in the study of whom 22 (11 female, 11 male) conducted all constant load time trials required for determining constant power threshold 30 min and 45 min, which is the highest power output constantly maintainable over 30 min and 45 min, respectively. Maximal lactate steady state was assessed subsequently from blood samples taken every 5 min during the time trials.
Results. Constant power threshold over 45 min (175.5 ± 49.6 W) almost matched power output at maximal lactate steady state (176.4 ± 50.5 W), whereas constant power threshold over 30 min (181.4 ± 51.4 W) was marginally higher ($P = 0.007$, $d = 0.74$). Interrelations between maximal lactate steady state and constant power threshold 30 min and constant power threshold 45 min were very close ($R^2 = 0.99$, SEE = 8.9 W, Percentage SEE (%SEE) = 5.1%, $P < 0.001$ and $R^2 = 0.99$, SEE = 10.0 W, %SEE = 5.7%, $P < 0.001$, respectively).
Conclusions. Determination of constant power threshold is a straining but viable and precise alternative for recreational cyclists to estimate power output at maximal lactate steady state and thus maximal sustainable oxidative metabolic rate.

Keywords

Time trial · Anaerobic threshold · Functional threshold · Cycling · Endurance exercise

but not for CVD. Post hoc analysis revealed significant differences between MLSS and CPT_{30} and between CPT_{30} and CPT_{45} for PO, BLC_{mean}, HR_{mean} and RPE. Differences between MLSS and CPT_{45} were not significant (**Table 3**).

A workload higher than PO at CPT_{30} is, by definition, not sustainable for 30 min. Time to exhaustion at the TT performed 10 W above CPT_{30} workload was 21.0 ± 6.4 min and BLC, HR and RPE at cessation of exercise were 8.40 ± 1.36 mmol · l^{-1}, 176.4 min^{-1} and 19.6 ± 0.7. At CPT_{30} workload, 11 participants had to terminate exercise between the 30th and 45th min (38.6 ± 6.9 min). The other 11 probands were able to maintain CPT_{30} workload for 45 min, which was the predefined maximum test duration. Accordingly, CPT_{30} and CPT_{45} workload were the same and time to exhaustion thus could not be determined. At the TT performed 10 W below CPT_{30} workload all participants except one were able to cycle for 45 min and BLC_{mean}, HR_{mean} and RPE were 5.19 ± 1.45 mmol · l^{-1}, 166.8 ± 9.4 min^{-1} and 16.5 ± 1.8, respectively. Differences to BLC_{mean}, HR_{mean} and RPE at CPT_{30} workload were all highly significant ($P < 0.001$) and effects sizes were large ($d = 1.46$, $d = 1.08$ and $d = 1.18$, respectively).

Interrelationships between PO at MLSS and PO at CPT_{30} ($R^2 = 0.99$, SEE = 8.9 W, %SEE = 5.1%, $P < 0.001$) as well as between PO at MLSS and PO at CPT_{45} ($R^2 = 0.99$, SEE = 10.0 W, %SEE = 5.7%, $P < 0.001$) were very close. Bland–Altman analysis revealed a bias of +3.3 for PO at CPT_{30} and +0.3% for PO at CPT_{45}. The 95% CI was ±15.6 W (±8.7%) and 18.6 W (±10.6%), respectively (**Figs. 1 and 2**).

Discussion

Motives for participating in recreational sports are multifaceted (Ebben & Brudzynski, 2008). For recreational cyclists striving among others to push their limit and improve performance, precise determination of AnT can supply useful information for designing training programs and defining appropriate exercise intensities. Hence, the aim of the present study was to investigate whether the CPT approach can be a beneficial alternative for recreational cyclists to assess AnT. The individual decision whether a method is regarded advantageous essentially is a trade-off between accuracy, on the one hand, and effort and practicability, on the other. Thus, in the first instance accuracy of the CPT approach is compared to existing methods for predicting AnT and thereafter discussed with a focus on effort and practicability. For evaluating accuracy, predominantly studies applying MLSS were used since MLSS is regarded one of the most valid criterion standard (Jones et al., 2019; Legaz-Arrese et al., 2011; Messias et al., 2017).

Accuracy of CPT approach in comparison to literature methods

R^2 for the interrelationship between prolonged TTs and MLSS range from 0.71 to 0.99 (Borszcz et al., 2019; Campbell et al., 2007; Harnish et al., 2001; Inglis et al., 2020; Lillo-Bevia et al., 2019). R^2 for the interrelation between lactate threshold and MLSS range from 0.31 to 0.90 and from 'not significant' to 0.95 for ventilatory threshold and MLSS (Figueira, Caputo, Pelarigo, & Denadai, 2008; Hauser, Adam, & Schulz, 2014; Heck, 1990; Laplaud, Guinot, Favre-Juvin, & Flore, 2006; MacIntosh, Esau, & Svedahl, 2002; Pallares, Moran-Navarro, Ortega, Fernandez-Elias, & Mora-Rodriguez, 2016; Peinado et al., 2016; Smekal et al., 2012; Van Schuylenbergh, Vanden Eynde, & Hespel, 2004; Zwingmann et al., 2019). In the present study, R^2 for the interrelationship between PO at CPT_{30} and PO at MLSS as well as between PO at CPT_{45} and PO at MLSS are $R^2 = 0.99$ and thus among the highest reported in the literature. Correlation parameters, however, are strongly influenced by the heterogeneity of the random sample and, furthermore, literature results are given in different units, both impeding comparison between studies. %SEE is considered to be the better parameter for comparing different methods and, thus, was predominantly applied for comparison reasons. If %SEE was not stated in literature, it was calculated from presented data.

Prolonged all-out TTs, which are well established for determining AnT and predicting competition performance, show the highest accuracy found in literature.

Table 2 Relative PO, BLC_{mean}, HR_{mean}, RPE and CVD at MLSS					
	Relative PO ($W \cdot kg^{-1}$)	**BLC_{mean} ($mmol \cdot l^{-1}$)**	**HR_{mean} (min^{-1})**	**RPE**	**CVD (min^{-1})**
All	2.46 ± 0.48	5.43 ± 1.57	167.2 ± 10.4	17.2 ± 1.6	6.1 ± 3.5
Female (*N* = 11)	2.34 ± 0.46	5.44 ± 1.10	173.1 ± 9.4	16.8 ± 1.7	6.2 ± 2.9
Male (*N* = 11)	2.57 ± 0.50	5.41 ± 1.99	161.3 ± 7.8	17.5 ± 1.6	6.0 ± 4.2
P/d[a]	Ns	Ns	0.004/1.13	Ns	Ns

BLC_{mean} mean blood lactate concentration, ***CVD*** cardiovascular drift, ***d*** Cohen's d, ***HR_{mean}*** mean heart rate from the 10th to 30th min, ***MLSS*** maximal lactate steady state, ***Ns*** not statistically significant, ***P*** probability, ***PO*** power output, ***RPE*** rate of perceived exertion
[a]differences between sexes

Table 3 PO, BLC_{mean}, HR_{mean}, RPE and CVD at MLSS, CPT_{30} and CPT_{45}				
		MLSS	**CPT_{30}**	**CPT_{45}**
PO	(W)	175.5 ± 50.2	181.4 ± 51.4	175.5 ± 49.6
	P/d[a]	0.007/0.74	–	< 0.001/1.00
BLC_{mean}	($mmol \cdot l^{-1}$)	5.43 ± 1.57	6.48 ± 1.31	5.75 ± 1.60
	P/d[a]	0.026/0.62	–	0.003/0.82
HR_{mean}	(min^{-1})	167.2 ± 10.4	173.1 ± 9.8	169.2 ± 11.1
	P/d[a]	0.027/0.61	–	0.012/0.69
RPE	–	17.2 ± 1.6	18.3 ± 1.5	17.1 ± 1.2
	P/d[a]	0.016/0.66	–	0.005/0.76
CVD	(min^{-1})	6.1 ± 3.5	6.3 ± 4.1	7.4 ± 5.0
	P/d[a]	Ns	–	Ns

BLC_{mean} mean blood lactate concentration, ***CPT_{30}*** constant power output maintainable over 30 min, ***CPT_{45}*** constant power output maintainable over 45 min, ***CVD*** cardiovascular drift, ***d*** Cohen's d, ***HR_{mean}*** mean heart rate from the 10th to 30th min, ***MLSS*** maximal lactate steady state, ***Ns*** not statistically significant, ***P*** probability, ***PO*** power output, ***RPE*** rate of perceived exertion
[a]differences to CPT_{30}

To the author's knowledge, capability of prolonged TTs for estimating PO at MLSS in cycling was subject to following studies, which were all performed on trained and well-trained athletes. %SEE for predicting MLSS from functional threshold power, defined as a certain percentage of the mean PO during a 20 min all-out cycling TT, range from 2.1% to 5.4% (Borszcz et al., 2019; Inglis et al., 2020; Lillo-Bevia et al., 2019). %SEE for 5 km TTs are 1.8% and 3.1% and for 40 km TTs 1.6% and 4.5% (Campbell et al., 2007; Harnish et al., 2001). Lactate and ventilatory threshold concepts based on incremental exercise tests are standard in laboratory testing. %SEE for predicting MLSS range from 1.0% to 12.5% for lactate thresholds and from 3.7% to 12.5% for ventilatory thresholds (Hauser et al., 2914; Heck, 1990; Laplaud et al., 2006; MacIntosh et al., 2002; Pallares et al., 2016; Peinado et al., 2016; Smekal et al., 2012; Van Schuylenbergh et al., 2004; Zwingmann et al., 2019). Further approaches for assessing AnT are critical power concept, HR variability threshold, Conconi's HR deflection point threshold and subjective rate of perceived exertion scores which record rather inconsistent results. %SEE for estimating MLSS from critical power ranges from 3.2% to insignificant (Dekerle, Baron, Dupont, Vanvelcena, & Pelayo, 2003; Maturana, Keir, McLay, & Murias, 2016; Okuno et al., 2011; Pringle & Jones, 2002) and from 6.7% to almost 16% for subjective rate of perceived exertion scores (Dos Santos et al., 2020; Madrid et al., 2016; Nakamura et al., 2009; Nakamura et al., 2008; Perandini et al., 2007). Weak as well as close interrelationships were found between HR variability threshold and ventilatory thresholds (Grannel & De Vito, 2018; Karpetian, Engels, & Gretebeck, 2008; Mankowski et al., 2017), while Conconi's test is also under controversial discussion due to contradictory study results (Assis Pereira de et al., 2016; Bodner, Rhodes, Martin, & Coutts, 2002; Bourgois et al., 2004; Carey, Raymond, & Duoos, 2002; Cook, 2011; Grazzi et al., 2008; Heck et al., 1989; Van Schuylenbergh et al., 2004). Finally, HR formulas are consistently regarded to not be capable of assessing AnT or training zones precisely (Knoepfli-Lenzin, Haenggli, & Boutellier, 2014; Mann et al., 2013; Röcker et al., 2002; Shen & Wen, 2019).

In the present study, %SEE for estimating PO at MLSS from PO at CPT_{30} and PO at CPT_{45} are 5.1% and 5.7%, respectively. Comparison reveals that accuracy of the CTP approach is only marginally lower than that of prolonged all-out TTs performed on experienced endurance athletes, at least as good as that of lactate and ventilatory threshold concepts and critical power method and even higher than that of HR variability threshold, Conconi's HR deflection point and subjective rate of perceived exertion scores. Moreover, it is worth mentioning that in the present study four of five participants whose PO at CPT_{45} exceeded PO at MLSS reached a BLC plateau during the last 20 min of exercise. However, we assessed MLSS as the highest PO at which BLC increased by no more than 1 $mmol \cdot l^{-1}$ between the 10th to 30th min of exercise because it is the most common definition. If we instead defined MLSS conditions during the last 20 min of exercise, four of the five participants would have kept MLSS conditions. Bias, SEE and %SEE would have been 3.2 W, 7.3 W and 4.1%, respectively, and just in one participant CPT_{45} would have exceeded PO at MLSS by 10 W. Hence, the risk of prescribing too high exercise intensities and thereby to induce overloading is very low. Precision could have been further increased by applying 5 W increments but 10 W increments are standard for MLSS determination and strain for participants would have been higher. Nevertheless, data clearly point out that the CPT approach is capable of precisely determining AnT in recreational athletes and to serve as a valid cornerstone for assessing training zones. The present results are in line with a study performed on recreational runners which found %SEE to be 2.6% for predicting MLSS speed from maximum constant running veloc-

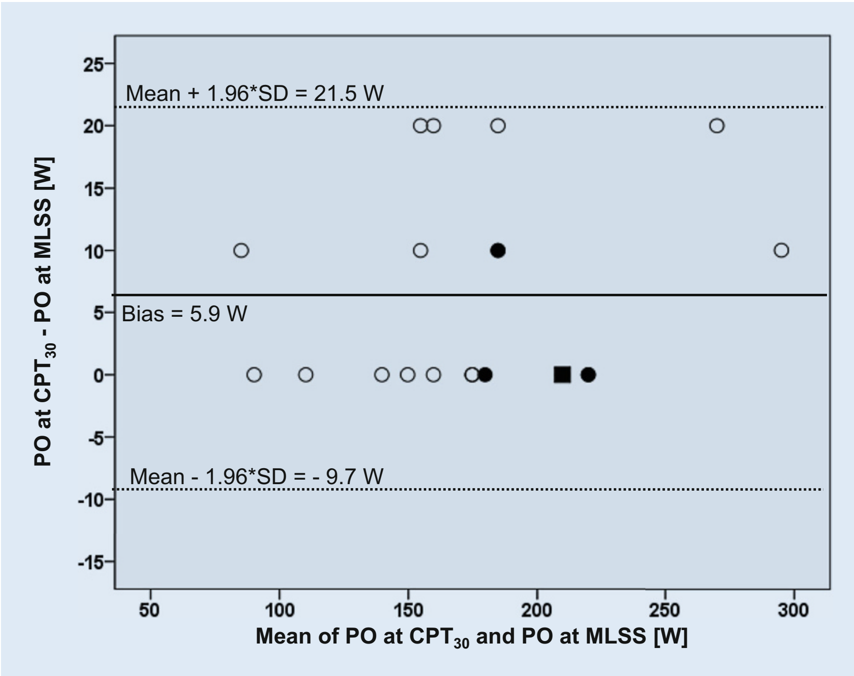

Fig. 1 ▲ Agreement between PO at CPT_{30} and PO at MLSS ($n = 22$). ● double data points, ■ triple data points, *PO* Power Output, *CPT_{30}* Constant Power Threshold over 30 min, *MLSS* Maximal Lactate Steady State

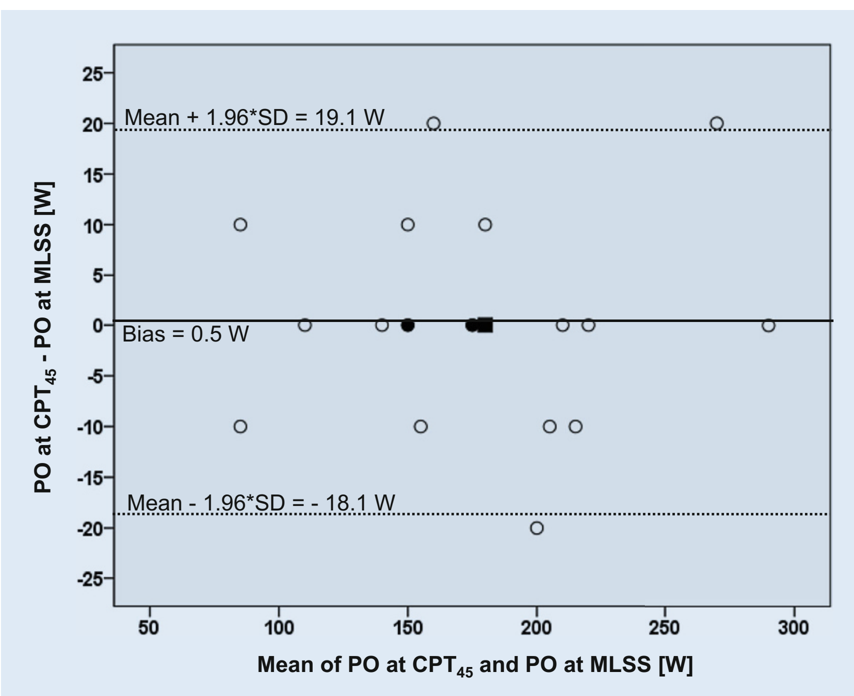

Fig. 2 ▲ Agreement between PO at CPT_{45} and PO at MLSS ($n = 22$). ● double data points, ■ triple data points, *PO* Power Output, *CPT_{45}* Constant Power Threshold over 45 min, *MLSS* Maximal Lactate Steady State

ity maintainable over 45 min (Vobejda, Wortmann, & Zimmermann, 2013).

Applicability of critical power approach and all-out TTs to recreational cyclists

As mentioned before, not only accuracy but also effort and practicability are further decisive factors determining suitability of methods for determining AnT. Accuracy of HR variability threshold, Conconi test and perceived exertion approaches appears insufficient for ambitious sportsmen and -women, and lactate and ventilatory threshold concepts require expert staff and expensive equipment, which most recreational cyclists do not have access to. Therefore, discussion is focussed on applicability of all-out TTs and critical power approach.

Critical power is reported to be higher than PO at MLSS so that mathematical corrections are necessary. Calculations are facilitated by customer friendly data calculators available in the internet but bear a noteworthy risk of errors since differences between critical power and MLSS range from minus 2% to plus 16.3% (Dekerle et al., 2003; Jones, 2019; Maturana et al., 2016; Okuno et al., 2011; Pallares et al., 2020). Moreover, determining critical power requires three to seven maximum-effort work bouts each inducing very high BLC and a feeling of discomfort. This is very challenging, particularly for low to moderately trained recreational cyclists who usually are not used to exercise in such high intensity zones limiting practicability for recreational athletes.

As stated before, studies investigating capability of prolonged all-out TTs for estimating AnT were almost exclusively conducted on trained cyclists. However, practicability to recreational athletes and transferability of these results is questionable due to following reasons. There is evidence that prolonged all-out TTs should last about 30 min to 75 min in order to render mathematical corrections unnecessary for calculating workload at AnT. A duration of 30 min to 75 min conforms to time to exhaustion at MLSS in recreational and trained cyclists (Baron et al., 2008; Dittrich, de Lucas, Beneke, &

Guglielmo, 2014; Fontana, Boutellier, & Knopfli-Lenzin, 2009; Grossl, Dantas De Lucas, Mendez de Souza, & Antonacci, 2012) and output almost equals workload at AnT (Borszcz et al., 2019; Harnish et al., 2001; Ham & Knez, 2009; McGhee et al., 2005). In contrast, at TTs shorter than 30 min average workload exceeds workload at AnT, whereas it falls below at TTs lasting longer than about 75 min (Borszcz et al., 2019; Lillo-Bevia et al., 2019; Campbell et al., 2007; Harnish et al., 2001; Sperlich et al., 2011), so that mathematical corrections are inevitable. Allen & Coggan (2010) recommended to correct power by the factor 0.95 but this factor is challenged (Inglis et al., 2020; MacInnis et al., 2019). Hence, calculating AnT from power output of TTs shorter or longer than about 30 min or 70 min is a source of errors and derogates accuracy of AnT determination. However, outcome of prolonged TTs is strongly influenced by the athletes' ability to adequately pace TTs (Foster et al., 1993; Ham & Knez, 2009; Koning de et al., 1999), but pacing prolonged TTs challenges even trained cyclists. Mattern et al. (2001) compared a predetermined slow starting pattern to the self-selected strategy in competitive cyclists and found the self-selected strategy to be unfavorable. Borszcz et al. (2019) investigated the relationship between the functional threshold power and PO at MLSS, but although all participants were experienced cyclists, test was preceded by a specific 50 min warm-up and must have been performed at least once before accuracy was markedly better in the well-trained than in the trained cyclists. In general, recreational athletes do not have specific experiences from TTs or competitions and thus are barely able to properly pace such trials. Finally, terrain and wind resistance strongly influence cycling velocity during field tests so that technical equipment such as power measuring devices are needed for accessing mean workload. Above that, most stationary bikes at home and in commercial fitness centers do not have the capability to compute mean workload. Due to aforementioned reasons, practicability of prolonged all-out TTs is regarded limited for recreational cyclists.

Applicability of the CPT approach to recreational cyclists

Athletes participating in the present study had only low to moderate aerobic capacities and the majority was not even practicing endurance sports. Determining workload of the first TT based on probands' self-report thus was only a first estimate and not necessarily close to MLSS. Accordingly, number of required TTs varied markedly from two to six. However, this methodology was applied in order to ensure transferability to practice of recreational sports. Procedure for determining CPT is doubtlessly very exhausting. It therefore has to be emphasized that high motivation and, in particular, good health is an inevitable prerequisite for conducting the required TTs. Moreover, a medical examination prior to testing is strongly recommended. Nevertheless, even though not encouraged during the TTs, 22 of 25 participants conducted all tests required for identifying CPT_{30} and CPT_{45}. One test person had to finish testing ahead of schedule due to illness. Only two probands refused to conduct the presumably final TT for confirming CPT. They argued that they could not maintain any higher workload and CPT thus was clearly identified. Hence, the vast majority of recreational athletes participating in the study were willing and able to withstand the strain.

PO at CPT_{45} almost equals PO at MLSS, whereas PO at CPT_{30} is 3.4% higher. Accordingly, shortening TT duration is not recommendable and determining CPT_{45} rather than CPT_{30} appears appropriate for recreational athletes in order to avoid error-prone mathematical correction. Yet, some factors mitigate overall burden. First, strain decreases notably once workload falls below PO at CPT_{30}. At a workload 10 W lower than CPT_{30}, corresponding to a reduction of about 5%, all participants were able to exercise for 45 min and RPE values decreased from 19.6 to 16.5. This conforms to the verbal feedback of most participants that at maximum two or three TTs were perceived very hard and that transition from sustainable to non-sustainable exercise occurred within a rather narrow and clearly perceptible intensity range. Second, in practice, time and effort can be further reduced. Number of TTs can be reduced by approximating AnT workload prior to CPT_{45} determination by means of less straining methods, such as HR variability threshold or Borg's rate of perceived exertion score. Third, CPT_{45} determination can be integrated into regular training programs since heavy to severe-intensity exercise bouts, which are generally an integral part of most endurance exercise programs designed for improving performance, can be replaced by TTs required for CPT_{45} determination. Cyclists who attach great importance to accuracy of AnT determination and are willing to accept the strain can further improve precision by determining CPT_{45} up to a precision of 5 W.

Furthermore, and in contrast to other methods for determining AnT, the cardiovascular drift, which is the HR increase in the course of constant load exercise (Coyle & Gonzales-Alonso, 2001), can be directly assessed during CPT determination and provide further helpful information for controlling endurance exercise intensity in the field.

Conclusions

Evidence is provided that determination of CPT_{45} is a viable and precise approach for young healthy recreational cyclists who value accurate assessment of MLSS as point of reference for prescribing endurance exercise intensity and assessing appropriate training zones. It is almost free of costs in that it only requires a regular HR monitor and power adjustable ergometers, which are standard in most fitness centers. Some recreational cyclists even have power measuring devices at their disposal. It does not require high aerobic capacity and, in contrast to traditional TTs, no specific pacing ability. However, it has to be pointed out that determining CPT_{45} is very exhausting and therefore requires high motivation and foremost good health. Moreover, study was carried out on participants in the third and fourth decade of age so that further research is needed in how far this approach is applicable to other groups of athletes.

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Declarations

Conflict of interest. C. Vobejda, T. Wortmann and E. Zimmermann declare that they have no competing interests.

All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee (Institutional ethics committee of the Medical Faculty of Ruhr University of Bochum, registered office: Heart and Diabetes Center Bad Oeynhausen, NRW) and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

References

Allen, H., & Coggan, A. (2010). *Training and racing with a power meter* (2nd edn.). Boulder: Velo Press.

Baron, B., Noakes, T. D., Dekerl, E. J., Moullan, F., Robin, S., Matran, R., & Pelayo, P. (2008). Why does exercise terminate at the maximal lactate steady state intensity? *British Journal of Sports Medicine*, *42*(1), 528–533. https://doi.org/10.1136/bjsm.2007.040444.

Beneke, R., Hutler, M., Von Duvillard, S. P., Sellens, M., & Leithauser, R. M. (2003). Effect of test interruptions on blood lactate during constant workload testing. *Medicine & Science in Sports & Exercise*, *35*(9), 1626–1630. https://doi.org/10.1249/01.MSS.0000084520.80451.D5.

Bentley, D. J., McNaughton, L. R., Thompson, D., & Vleck, V. E. (2001). Peak power output, the lactate threshold, and TT performance in cyclists. *Medicine & Science in Sports & Exercise*, *33*(12), 2077–2081. https://doi.org/10.1097/00005768-200112000-00016.

Bland, J. M., & Altman, D. G. (1999). Measuring agreement in method comparison studies. *Statistical Methods in Medical Research*, *8*(2), 135–160. https://doi.org/10.1177/096228029900800204.

Bodner, M. E., Rhodes, E. C., Martin, A. D., & Coutts, K. D. (2002). The relationship of the heart rate deflection point to the ventilatory threshold in trained cyclists. *Journal of Strength and Conditioning Research*, *16*(4), 573–580.

Borszcz, F. K., Ferreira Tramontin, A., & Pereira Costa, V. (2019). Is the functional threshold power interchangeable with the maximal lactate steady state in trained cyclists? *International Journal of Sports Physiology and Performance*, *14*(8), 1029–1035. https://doi.org/10.1123/ijspp.2018-0572.

Bourgois, J., Coorevits, P., Danneels, L., Witvrouw, E., Cambier, D., & Vrijens, J. (2004). Validity of the heart rate deflection point as a predictor of lactate threshold concepts during cycling. *Journal of Strength and Conditioning Research*, *18*(3), 498–503. https://doi.org/10.1519/1533-4287(2004)18⟨498:VOTHRD⟩2.0.CO;2.

Burnley, M., Doust, J. H., & Vanhatlo, A. (2006). A 3-min all-out test to determine peak oxygen uptake and the maximal lactate steady state. *Medicine & Science in Sports & Exercise*, *38*(11), 1996–2003. https://doi.org/10.1249/01.mss.0000232024.06114.a6.

Campbell, C. S. G., Sousa, W. H., Ferreira, J. N., Assenço, F., & Simoes, H. G. (2007). Prediction of maximal lactate steady state velocity based on performance in a 5 km cycling test. *Revista Brasileira De Cineantropometria Desempenho Humano*, *9*(3), 223–230.

Carey, D. G., Raymond, R. L., & Duoos, B. A. (2002). Intra- and inter-observer reliability in selection of the heart rate deflection point during incremental exercise: Comparison to a computer-generated deflection point. *Journal of Sports Science and Medicine*, *1*(4), 115–121.

Cook, I. (2011). Was the Conconi test validated by sporting success, expert opinion or good science? *South African Journal for Research in Sport Physical Education and Recreation*, *33*(1), 23–35. https://doi.org/10.4314/sajrs.v33i1.65483.

Coyle, E. F., & Gonzales-Alonso, J. (2001). Cardiovascular drift during prolonged exercise: new perspectives. *Exercise and Sports Sciences Review*, *29*(2), 88–92. https://doi.org/10.1097/00003677-200104000-00009.

Deelen, I., Ettema, D., & Kamphuis, C. B. M. (2018). Sport participation in sport clubs, gyms, or public spaces: how users of different sport settings differ in their motivation, goals, and sport frequency. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0205198.

Dekerle, J., Baron, B., Dupont, L., Vanvelcena, J., & Pelayo, P. (2003). Maximal lactate steady state, respiratory compensation threshold and critical power. *European Journal of Applied Physiology*, *89*(3-4), 281–288. https://doi.org/10.1007/s00421-002-0786-y.

Dittrich, N., de Lucas, R. D., Beneke, R., & Guglielmo, L. G. (2014). Time to exhaustion at continuous and intermittent maximal lactate steady state during running exercise. *International Journal of Sports Physiology and Performance*, *9*(5), 772–776. https://doi.org/10.1123/ijspp.2013-0403.

Dos Santos, G. A., Numata-Filho, E. S., Dos, S. R. T., Neves, R. V. P., Simões, H. G., & Rodrigues Moreira, S. (2020). Anaerobic threshold determination in cycle ergometer from rating of perceived exertion. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000003627.

Ebben, W., & Brudzyinski, L. (2008). Motivations and barriers to exercise among college students. *Journal of Exercise Physiology online*, *11*(5), 1–11.

Figueira, T. R., Caputo, F., Pelarigo, J. G., & Denadai, B. S. (2008). Influence of exercise mode and maximal lactate-steady-state concentration on the validity of OBLA to predict maximal lactate-steady-state in active individuals. *Journal of Science and Medicine in Sport*, *11*(3), 280–286. https://doi.org/10.1016/j.jsams.2007.02.016.

Fontana, P., Boutellier, U., & Knopfli-Lenzin, C. (2009). Time to exhaustion at maximal lactate steady state is similar for cycling and running in moderately trained subjects. *European Journal of Applied Physiology*, *107*(2), 187–192. https://doi.org/10.1007/s00421-009-1111-9.

Foster, C., Snyder, A. C., Thompson, N. N., Green, M. A., Foley, M., & Schrager, M. (1993). Effect of pacing strategy on cycle time trial performance. *Medicine & Science in Sports & Exercise*, *25*(3), 383–388.

Gill, D. L., Dowd, D. A., Williams, L., Beaudoin, C. M., & Martin, J. J. (1996). Competitive orientations and motives of adult sport and exercise participants. *J Sport Behav*, *19*(4), 307–318.

Grannell, A., & De Vito, G. (2018). An investigation into the relationship between heart rate variability and the ventilatory threshold in healthy moderately trained males. *Clinical Physiology and Functional Imaging*, *38*(3), 455–461. https://doi.org/10.1111/cpf.12437.

Grazzi, G., Mazzoni, G., Casoni, I., Uliari, S., Collini, G., van der Heide, L., & Conconi, F. (2008). Identification of a Vo2 deflection point coinciding with the heart rate deflection point and ventilatory threshold in cycling. *Journal of Strength and Conditioning Research*, *22*(4), 1116–1123. https://doi.org/10.1519/JSC.0b013e318173936c.

Groslambert, A., Grappe, F., Bertucci, W., Perrey, S., Girard, A. J., & Rouillon, J. D. (2004). A perceptive individual time trial performed by triathletes to estimate the anaerobic threshold. *Journal of Sports Medicine and Physical Fitness*, *44*(2), 147–156.

Grossl, T., Dantas de Lucas, R., Mendez de Souza, K., & Antonacci, G. L. G. (2012). Time to exhaustion at intermittent maximal lactate steady state is longer than continuous cycling exercise. *Applied Physiology, Nutrition, and Metabolism*, *37*(6), 1047–1053. https://doi.org/10.1139/h2012-088.

Ham, D. J., & Knez, W. L. (2009). An evaluation of 30-km cycling TT (TT30) pacing strategy through time-to-exhaustion at average TT30 pace. *Journal of Strength and Conditioning Research*, *23*(3), 1016–1021. https://doi.org/10.1519/JSC.0b013e3181a30f8f.

Harnish, C. R., Swensen, T. C., & Pate, R. R. (2001). Methods for estimating the maximal lactate steady state in trained cyclists. *Medicine & Science in Sports & Exercise*, *33*(6), 1052–1055. https://doi.org/10.1097/00005768-200106000-00027.

Harriss, D. J., & Atkinson, G. (2019). Ethical standards in sport and exercise science research: 2020 Update. *International Journal of Sports Medicine*, *40*(13), 1025–1028. https://doi.org/10.1055/a-1015-3123.

Hauser, T., Adam, J., & Schulz, H. (2014). Comparison of selected lactate threshold parameters with maximal lactate steady state in cycling. *International Journal of Sports Medicine*, *35*(6), 517–521. https://doi.org/10.1055/s-0033-1353176.

Heck, H. (1990). *Laktat in der Leistungsdiagnostik (Lactate in endurance diagnostics)*. Schorndorf: Verlag Karl Hofmann.

Heck, H., Beckers, K., Lammerschmidt, E., Pruin, E., Hess, G., & Hollmann, W. (1989). Determinability, objectivity, and validity of the Conconi threshold on the cycle ergometer (Bestimmbarkeit, Objektivität und Validität der Conconi-Schwelle auf dem Fahrradergometer). *Deutsche Zeitschrift für Sportmedizin*, *40*(11), 388–402.

Inglis, C. E., Ianetta, D., Passfield, L., & Murias, J. M. (2020). Maximal lactate steady state versus the 20-minute functional threshold power test in well-trained individuals. "Watts" the big deal? *International Journal of Sports Physiology and Performance*, *15*, 541–547. https://doi.org/10.1123/ijspp.2019-0214.

Jeffries, O., Simmons, R., Patterson, S. D., & Waldron, M. (2019). Functional threshold power is not equivalent to lactate parameters in trained cyclists. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000003203.

Jones, A. M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine*, *29*(6), 373–386. https://doi.org/10.2165/00007256-200029060-00001.

Jones, A. M., Burnley, M., Black, M. I., Poole, D. C., & Vanhatalo, A. (2019). The maximal metabolic steady state: redefining the 'gold standard. *Physiological Reports*, *7*(10), 1–15. https://doi.org/10.14814/phy2.1409.

Karpetian, G. K., Engels, H. J., & Gretebeck, R. J. (2008). Use of heart rate variability to estimate LT and VT. *International Journal of Sports Medicine*, *29*(8), 652–657. https://doi.org/10.1055/s-2007-989423.

Knoepfli-Lenzin, C., Haenggli, B., & Boutellier, U. (2014). Optimised heart rate formulae to monitor endurance training in sedentary individuals. *Journal of Sports Sciences*, *32*(6), 557–562. https://doi.org/10.1080/02640414.2013.843015.

de Koning, J. J., Bobbert, M. F., & Foster, C. (1999). Determination of optimal pacing strategy in track cycling with energy flow model. *Journal of Science and Medicine in Sport*, *2*(3), 266–277. https://doi.org/10.1016/s1440-2440(99)80178-9.

Kraus, I., Katzmarek, U., Rieger, M. A., Sudeck, G. (2017) Motives for physical exercise participation as a basis for the development of patient-oriented exercise interventions in osteoarthritis: a cross-sectional study. *European Journal of Physical and Rehabilitation Medicine*, 53(4), 590–602. https://doi.org/10.23736/S1973-9087.17.04482-3.

Laplaud, D., Guinot, M., Favre-Juvin, A., & Flore, P. (2006). Maximal lactate steady state determination with a single incremental test exercise. *European Journal of Applied Physiology*, *96*(4), 446–452. https://doi.org/10.1007/s00421-005-0086-4.

Legaz-Arrese, A., Carranza-García, L. E., Serrano-Ostáriz, E., González-Ravé, J. M., & Terrados, N. (2011). The traditional maximal lactate steady state test versus the 5×2000-m test. *International Journal of Sports Medicine*, *32*(11), 845–850. https://doi.org/10.1055/s-0031-1283178.

Ley, C. (2020). Participation motives of sport and exercise maintainers: Influences of age and gender. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph17217830.

Lillo-Bevia, J. R., Courel-Ibanez, J., Cerezuela-Espejo, V., Moran-Navarro, R., Martinez-Cava, A., & Pallares, J. G. (2019). Is the functional threshold power a valid metric to estimate the maximal lactate steady state in cyclists? *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000003403.

MacIntosh, B. R., Esau, S., & Svedahl, K. (2002). The lactate minimum test for cycling: Estimation of the maximal lactate steady state. *Canadian Journal of Applied Physiology*, *27*(3), 232–249. https://doi.org/10.1139/h02-014.

Madrid, B., Pires, F. O., Prestes, J., Vieira, D. C. L., Clark, T., Tiozzo, E., Lewis, J. E., Grubert, C. C. S., & Simões, H. G. (2016). Estimation of maximal lactate steady state intensity by the rating of perceived exertion. *Perceptual and Motor Skills*, *122*(1), 136–149. https://doi.org/10.1177/0031512516631070.

Mankowski, R. T., Michael, S., Rozenberg, R., Stokla, S., Stam, H. J., & Praet, S. F. E. (2017). Heart rate variability threshold is an alternative to spiro-ergometry testing: A validation study. *Journal of Strength and Conditioning Research*, *31*(2), 474–479. https://doi.org/10.1519/JSC.0000000000001502.

Mann, T., Lamberts, R. P., & Lambert, M. I. (2013). Methods of prescribing relative exercise intensity: physiological and practical considerations. *Sports Medicine*, *43*(7), 613–625. https://doi.org/10.1007/s40279-013-0045-x.

Mattern, C. O., Kenefick, R. W., Kertzer, R., & Quinn, T. J. (2001). Impact of starting strategy on cycling performance. *International Journal of Sports Medicine*, *22*(5), 350–355. https://doi.org/10.1055/s-2001-15644.

Maturana, F. M., Keir, D. A., McLay, K. M., & Murias, J. M. (2016). Can measures of critical power precisely estimate metabolic lactate steady state? *Applied Physiology, Nutrition and Metabolism*, *41*(11), 1197–1203. https://doi.org/10.1139/apnm-2016-0248.

McGhee, J. C., Tanner, C. J., & Houmard, J. A. (2005). A comparison of methods for estimating the lactate threshold. *Journal of Strength and Conditioning Research*, *19*(3), 553–558. https://doi.org/10.1519/15444.1.

McGrath, E., Mahony, N., Fleming, N., Raleigh, C., & Donne, B. (2021). Do critical and functional threshold powers equate in highly-trained athletes? *Int J Exerc Sci*, *14*(4), 45–59.

MacInnis, M. J., Thomas, A. C. Q., Phillips, S. M. (2019). The Reliability of 4-Minute and 20-Minute Time Trials and Their Relationships to Functional Threshold Power in Trained Cyclists. *International Journal of Sports Physiology and Performance*. 14(1), 38–45. https://doi.org/10.1123/ijspp.2018-0100.

Messias, L. H. D., Gobatto, C. A., Beck, W. R., & Manchado-Gobatto, F. B. (2017). The lactate minimum test: concepts, methodological aspects and insights for future investigations in human and animal models. *Frontiers in Physiology*. https://doi.org/10.3389/fphys.2017.00389.

Molanorouzi, K., Khoo, S., & Morris, T. (2015). Motives for adult participation in physical activity: type of activity, age, and gender. *BMC Public Health*. https://doi.org/10.1186/s12889-015-1429-7.

Nakamura, F. Y., Okuno, N. M., Perandini, L. A. B., Caldeira, L. F. S., Simões, H. G., Cardoso, J. R., & Bishop, D. J. (2008). Critical power can be estimated from nonexhaustive tests based on rating of perceived exertion responses. *Journal of Strength and Conditioning Research*, *22*(3), 937–943. https://doi.org/10.1519/JSC.0b013e31816a41fa.

Nakamura, F. Y., Okuno, N. M., Perandini, L. A. B., de Oliveira, F. R., Buchheit, M., & Simões, H. G. (2009). Perceived exertion threshold: comparison with ventilatory thresholds and critical power. *Science and Sports*, *24*(3), 196–201. https://doi.org/10.1016/j.scispo.2008.07.003.

Nikolaidis, P. T., Chalabaev, A., Rosemann, T., & Knechtle, B. (2019). Motivation in the Athens classic marathon: the role of sex, age, and performance level in Greek recreational marathon runners. *International Journal of Environmental Research and Public Health*, *16*, 2549. https://doi.org/10.3390/ijerph16142549.

Okuno, N. M., Perandini, L. A. B., Bishop, D., Simões, H. G., Pereira, G., Berthoin, S., Kokubun, E., & Nakamura, F. Y. (2011). Physiological and perceived exertion responses at intermittent critical power and intermittent maximal lactate steady state. *Journal of Strength and Conditioning Research*, *25*(7), 2053–2058. https://doi.org/10.1519/JSC.0b013e3181e83a36.

Pallares, J. G., Moran-Navarro, R., Ortega, J. F., Fernandez-Elias, E., & Mora-Rodriguez, R. (2016). Validity and reliability of ventilatory and lactate threshold in well-trained cyclists. *PLoS One*. https://doi.org/10.1371/journal.pone.0163389.

Pallares, J. G., Lillo-Bevia, J. R., Moran-Navarro, R., Cerezuela-Espejo, V., Mora-Rodriguez, R. (2020). Time to exhaustion during cycling is not well predicted by critical power calculations. *Applied Physiology, Nutrition and Metabolism*, 45(7), 753–760. https://doi.org/10.1139/apnm-2019-0637.

Peinado, A. B., Pessoa Filho, D. M., Diaz, V., Benito, P. J., Alvarez-Sanchez, M., Zapico, A. G., & Calderon, F. J. (2016). The midpoint between ventilatory thresholds approaches maximal lactate steady state in amateur cyclists. *Biology of Sport*, *33*(4), 373–380. https://doi.org/10.5604/20831862.1221812.

Perandini, L. A. B., Okuno, N. M., Müller Hirai, D., Simões, H. G., Cyrino, E. S., & Nakamura, F. Y. (2007). Comparison between perceived exertion threshold and indicators of maximal lactate steady state in intermittent exercise. *Revista*

Brasileira De Cineantropometria E Desempenho Humano, *9*(4), 351–357.
Pereira, A. P. E. de, Piubello Carrara, V. K., Mello Rissato, G., Pereira, D. J. M., Guerra, R., & Azevedo, P. (2016). The relationship between the heart rate deflection point test and maximal lactate steady state. *Journal of Sports Medicine and Physical Fitness*, *56*(5), 497–502.
Pringle, J. S. M., Jones, A. M. (2002). Maximal lactate steady state, critical power and EMG during cycling. *European Journal of Applied Physiology*, 88(3), 214–226. https://doi.org/10.1007/s00421-002-0703-4.
Röcker, K., Niess, A. M., Horstmann, T., Striegel, H., Mayer, F., Dickhuth, H. H. (2002). Heart rate prescriptions from performance and anthropometrical characteristics. *Medicine & Science in Sports & Exercise*, 34(5), 881–887. https://doi.org/10.1097/00005768-200205000-00024.
Shen, T., & Wen, X. (2019). Heart-rate based prediction of velocity at lactate threshold in ordinary adults. *Journal of Exercise Science and Fitness*, *17*(3), 108–112. https://doi.org/10.1016/j.jesf.2019.06.002.
Smekal, G., von Duvillard, S. P., Pokan, R., Hofmann, P., Braun, W. A., Arciero, P. J., Tschan, H., Wonisch, M., Baron, R., & Bachl, N. (2012). Blood lactate concentration at the maximal lactate steady state is not dependent on endurance capacity in healthy recreationally trained individuals. *European Journal of Applied Physiology*, *112*(8), 3079–3086. https://doi.org/10.1007/s00421-011-2283-7.
Sperlich, B., Haegele, M., Thissen, A., Mester, J., & Holmberg, H. C. (2011). Are peak oxygen uptake and power output at maximal lactate steady state obtained from a 3-min all-out cycle test? *International Journal of Sports Medicine*, *32*(6), 433–437. https://doi.org/10.1055/s-0031-1271770.
Swensen, T. C., Harnish, C. R., Beitman, L., & Keller, B. A. (1999). Noninvasive estimation of the maximal lactate steady state in trained cyclists. *Medicine & Science in Sports & Exercise*, *31*(5), 742–746. https://doi.org/10.1097/00005768-199905000-00019.
Van Schuylenbergh, R., Vanden Eynde, B., & Hespel, P. (2004). Correlations between lactate and ventilatory thresholds and the maximal lactate steady state in elite cyclists. *International Journal of Sports Medicine*, *25*(6), 403–408. https://doi.org/10.1055/s-2004-819942.
Vobejda, C., Wortmann, T., & Zimmermann, E. (2013). Maximal constant 45 min running velocity gives maximal lactate steady state. *Journal of Sports Medicine and Physical Fitness*, *53*(6), 588–595.
Zwingmann, L., Strütt, S., Martin, A., Volmary, P., Bloch, W., & Wahl, P. (2019). Modifications of Dmax method in comparison to maximal lactate steady state in young athletes. *The Physician and Sportsmedicine*, *47*(2), 174–181. https://doi.org/10.1080/00913847.2018.1546103.